치의과학 박사학위논문

Comparative Analysis on Initial Stability and Clinical Applicability of Zirconia and Titanium Alloy Orthodontic Micro-implants

지르코니아와 타이타니움 합금 교정용 마이크로 임플란트의 초기 안정성과 임상 적용성에 관한 비교 연구

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서울대학교 대학원
치의과학과 치과생체재료과학 전공
최 혜 원

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지도교수 이 상 훈

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서울대학교 대학원
치의과학과 치과생체재료과학 전공
최 혜 원

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위 원 장	임 범 순	(인)
부 위 원 장	이 상 훈	(인)
위 원	안 진 수	(인)
위 원	권 오 형	(인)
위 원	박 원 호	(인)

Abstract

Comparative Analysis on Initial Stability and Clinical Applicability of Zirconia and Titanium Alloy Orthodontic Micro-implants

Division of Dental Biomaterials Science
Department of Dental Science, Graduate School
Seoul National University
(Directed by Prof. Sang-Hoon Rhee)

Hae Won Choi

The aim of this study was to compare the initial stability as insertion and removal torque and the clinical applicability of novel orthodontic zirconia micro-implants made using powder injection molding (PIM) technique with those parameters in conventional titanium micro-implants. Sixty zirconia and 60 titanium alloy micro-implants of similar design (1.6-mm diameter, 8.0-mm length) were inserted perpendicularly in solid polyurethane foam with varying densities of 20 pounds per cubic foot (pcf), 30 pcf, and 40 pcf. Primary stability was measured as maximum insertion torque (MIT) and maximum removal torque (MRT). To investigate clinical applicability, compressive and tensile forces were recorded at 0.01 mm, 0.02 mm, and 0.03 mm displacement of the micro-implants at angles of 0°, 10°, 20°, 30°, and 40°. The biocompatibility of zirconia micro-implants was assessed via an experimental animal study. There were no statistically significant differences between zirconia micro-implants and titanium alloy implants with regard to MIT, MRT, or the amount of movement in the angulated lateral displacement test. As angulation increased, the mean compressive and tensile forces required to displace both type of micro-implants increased substantially at all distances. The average bone-to-implant contact ratio of prototype of zirconia micro-implants was 56.88 ± 6.72%. Zirconia micro-implants showed comparable initial stability and clinical applicability to that of titanium micro-implants for diverse orthodontic treatments, under compressive and tensile forces.

Keywords: Micro-implants, Zirconia implant, Temporary anchorage device, Mechanical stability

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1. Introduction

The use of orthodontic micro-implants or temporary anchorage device (TAD) has increased in popularity during orthodontic treatment for reinforcement of anchorage without reliance on patient compliance. [1] Recent researches showed success rate greater than 80%, however failure of micro-implants as loss of stability is a multifactorial problem. [2, 3] The factors that affect the success rate of micro-implants are reported about, such as bone quality, inflammation and breakage of implant tips. [2, 4]

Regarding as short- and long-term micro-implant stability, primary stability is affected by the bone density of the surrounding cortical bone, screw type, and screw position, whereas extended stability is influenced by new bone growth around micro-implants. [5] Partial osseointegration of micro-implants could improve stability and resistance to orthodontic loading as it has been observed in various studies, [5-7] even though complete osseointegration is not prerequisite in orthodontic micro-implants. [3]

Zirconia implants have been introduced in implant dentistry as a substitute to titanium alloy implants because of potentially lower susceptibility to bacterial adhesion, biologic favorable response to the tissue, higher esthetics, and biocompatibility that results in osseointegration. [8, 9] Researchers reported that ceramic particles induce less inflammatory response and bone resorption than titanium particles suggesting the biocompatibility of ceramics, [10] in addition to no chemical or physical bonding with plaque and low affinity to bacterial colonization. [11, 12] Recent research proclaimed that zirconia showed lower bacterial colonization than titanium, which could decrease the initial adhesion of microorganisms to reduce the prevalence and progression of oral infections. [13]

Conventionally, zirconia implants have typically been machined with or without surface treatment, whereas a few studies showed that surface-treated implants made using low pressure injection molding technique. [14] Recently, a novel method of powder injection molding (PIM) technique was presented, which uses a mold with a roughened inner surface and removes the need for additional surface treatment procedures to enhance the mechanical property of the implant surface. [15]

In this study, novel zirconia micro-implants was produced using PIM technique and the mechanical properties such as primary stability and clinical usability were examined. The initial stability is often quantified by insertion torque. [16] For clinical usability test, the lateral displacement test to measure the angulated compressive and tensive force required for displacement of micro-implants was performed to simulate forces applied to the micro-implants under diverse clinical conditions. [17, 18]

The aim of the current study was to compare the stability as insertion and removal torque and biocompatibility of novel zirconia micro-implants made using a PIM technique with those parameters in the conventional titanium micro-implants. We hypothesized that zirconia and titanium alloy micro-implants would produce comparable values as indicators of mechanical stability and clinical applicability.

2. Materials and Methods

2.1. *Implant design*

Zirconia micro-implants (diameter 1.6 mm, length 8.0 mm, single threading) were created using a PIM technique with a roughened mold (Y-TZP, Ceta-tech, Daegu, Korea), and titanium alloy (Orlus, Ti6Al4V Ortholution, Seoul, Korea) self-threading micro-implants of a similar design were prepared (Figure 1). The Chemical composition and mechanical properties of zirconia and titanium alloy are shown in Table 1. Scanning electron microscopy (SEM) (S-4700 Hitachi, Tokyo, Japan) was utilized to examine qualitative surface topography.

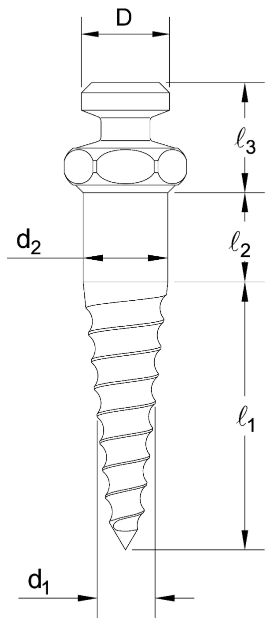

Fig. 1.

Macro-design of zirconia micro-implants used in the experiment (tapered shape with a diameter of 1.6 mm and a length of 8.0 mm, single threading).

Table 1. Chemical Composition and Mechanical Properties of Titanium Alloy and Zirconium Alloy (www.matweb.com/search/DataSheet.aspx).

Chemical Composition, %											Mechanical Properties				
											Tensile Strength (MPa)	Young's Modulus (GPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Hardness (GPa)
Alloy	N	C	H	O	Fe	Al	V	Ti	Hafnium	Zirconium					
Ti-6Al-4V	0.05	0.08	0.012	0.13	0.25	5.5-6.5	3.5-4.5	Balance	-	-	860-896	110	795-827	1500	
Y-TZP ZrO2	0.3	-	0.005	0.3	0.3	13.2	-	-	4.5	Balance	700	200-250	5200	900-1200	13.2

2.2. Torque test

In the insertion torque test, 60 zirconia micro-implants and 60 titanium micro-implants were inserted into solid rigid polyurethane foam (Sawbones, Vashon, Wash) and removed using a surgical engine and contra-angle handpiece (Elcomed SA200C, W&H, Austria) by one technician. The surgical engine was calibrated before testing, and rotational speed was set to 30 rpm. The polyurethane foam was composed of cortical bone simulant (SRPF) of 2-mm thick 20, 30, and 40 pounds per cubic foot (pcf), [18] and the trabecular bone part (CRPF) was composed of 10 pcf (Table 2). Soft tissue was simulated with a 1-mm thick plastic sheet covering. All micro-implants were inserted perpendicularly to the bone simulant surface. Maximum insertion torque (MIT) and maximum removal torque (MRT) were measured.

Table 2. Mechanical Properties of Polyurethane Foam for the Insertion of the Micro-implants[a].

Material	Density		Compressive		Tensile		Shear		Cell Size (mm)
	Pcf	g/cc	S(MPa)	M(MPa)	S(MPa)	M(MPa)	S(MPa)	M(MPa)	
SRPF	20	0.3	8.4	210	5.6	284	4.3	49	-
	30	0.5	18	445	12	592	7.6	87	-
	40	0.6	31	759	19	1000	11	130	-
CRPF	10	0.2	2.3	23	-	-	-	-	0.5-2.0

[a]SRPF, solid rigid polyurethane foam; CRPF, cellular rigid polyurethane foam; S, strength; M, modulus; pcf, pounds per cubic foot.

2.3. Angulated displacement test

For each material group, 15 new micro-implants were inserted using a surgical engine for angulated displacement tests and for both compressive and tensile forces. The polyurethane foam with micro-implants was positioned to deliver a force to the neck of the micro-implants with varying angulations of 0°, 10°, 20°, 30° and 40° with respect to the line perpendicular to the long axis of the micro-implants, fixed in a vice. Lateral displacement testing was then performed using compressive and tensile modes of a universal testing machine (Instron 4465; Instron, Norwood, MA, USA) with customized loading pins. [18] Software (Bluehill® version 2.0; Instron) was used to record the force value with a 1 kN load cell when implants were displaced by 0.01, 0.02, and 0.03 mm from their original position.

2.4. Experimental animal study

Three 3-month-old male New Zealand White rabbits were used in the experimental animal study. All the animal study protocols were approved by the Institutional Animal Care and Use Committee of Seoul National University, Seoul, Korea. (SNU-160615-3)

2.4.1. Surgical procedures

A total of 12 prototype zirconia micro-implants were placed in the hind legs of the animals following pilot site preparation with copious saline irrigation. Two prototype zirconia micro-implants were placed into each tibial metaphysis.

2.4.2. Postsurgical procedures and animal sacrifice

Rabbits were sacrificed 4 weeks after prototype zirconia micro-implant placement. Block bone biopsy specimens with zirconia micro-implant sites were collected, fixed in 10% buffered formalin, and processed for histomorphometric analysis.

2.5. Histomorphometric analysis

Embedded specimens with zirconia micro-implants were cut in a mid-axial apico-coronal plane using a macro cutting and grinding technique (EXAKT310 CP series, EXACT Apparatebau, Oklahoma City, OK, USA). Captured digital images of hematoxylin eosin-stained undecalcified specimens were used to quantify the percentages of bone-to-implant contact (BIC) within the cortical resident bone using image analysis software (KAPPA, Opto-electronics GmbH, Kelines Feld, Germany). [15]

2.6. Statistical methods

Mean MIT and MRT measurements were statistically evaluated via the independent t-test to assess differences between the zirconia and titanium alloy groups, and $p < 0.05$ was deemed to indicate statistical significance. Mean force levels for each lateral displacement distance were compared across implant materials and angulation using independent t-tests and one-way analysis of variance (ANOVA). Two-way ANOVA was then performed in order to assess interactions between micro-implant materials and angulations. Statistical analyses were performed using statistical software (SPSS for Windows, version 16.0; SPSS, Chicago, III). Means and standard deviations were recorded.

3. Results

3.1. Surface characteristics

SEM micrographs demonstrated microstructures for zirconia micro-implants with roughened topography. Images of zirconia surfaces derived using a roughened mold exhibited elevations and depressions in addition to the grain structure (Figure 2), compared with the titanium alloy (Figure 3).

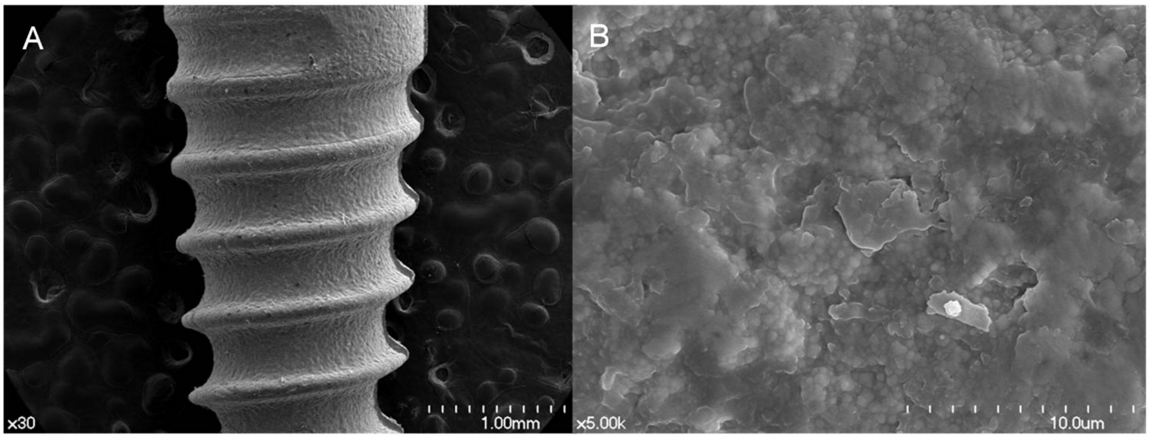

Fig. 2.

SEM micrographs of tested zirconia micro-implants; (A) Enlargement 100-fold, (B) Enlargement 5000-fold.

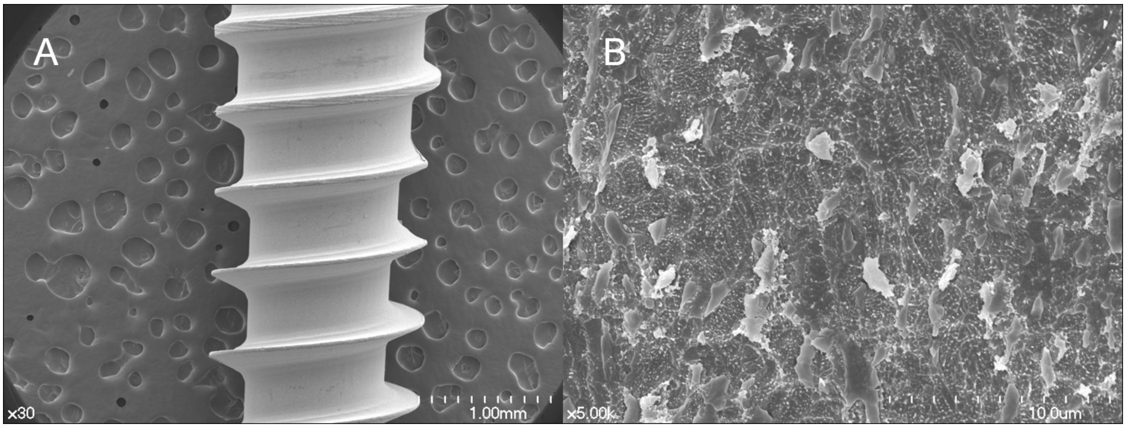

Fig. 3.

SEM micrographs of tested titanium alloy micro-implants; (A) Enlargement 30-fold, (B) Enlargement 5000-fold.

3.2. Torque test

All zirconia and titanium alloy micro-implants remained stable, without fracturing during this study. There were no statistically significant differences in mean MIT or MRT at cortical bone densities of 20, 30, or 40 pcf between zirconia and titanium alloy micro-implants (Figure 4, Table 3). For both types of micro-implants, the MRT was lower than the MIT in all groups, and 40 pcf cortical bone required the highest MIT and MRT (Figure 4, Table 3).

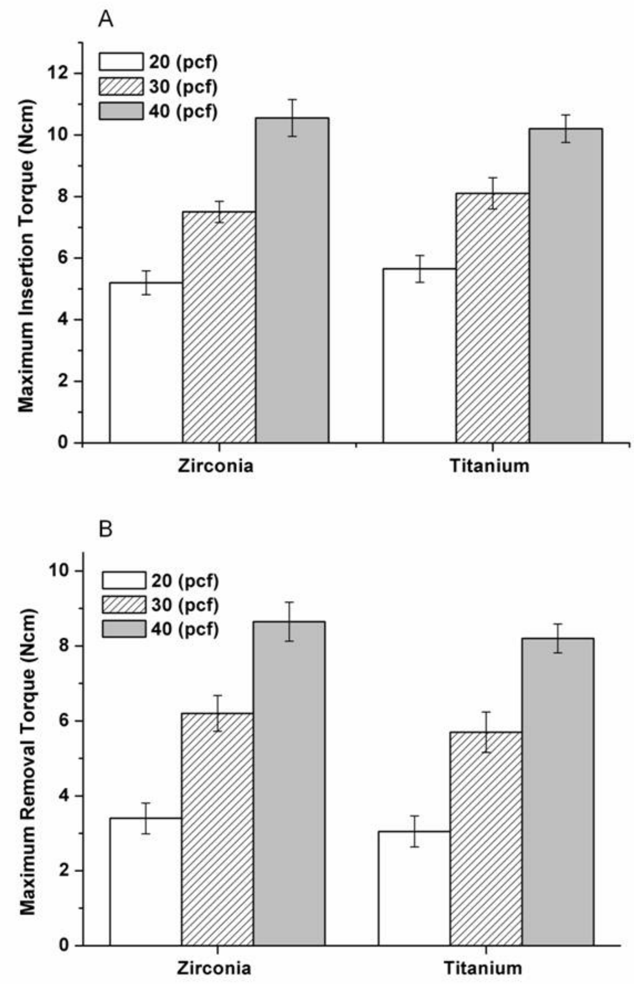

Fig. 4.

Mean measurements of (A) maximum insertion torque and (B) maximum removal torque.

Table 3. Maximum Insertion Torque (MIT, Mean Ncm ± SD) and Maximum Removal Torque (MRT, Mean Ncm ± SD) of Each Group.

Material	MIT					MRT				
Bone Density (pcf)	Zirconia		Titanium		*p*-value	Zirconia		Titanium		*p*-value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
20 (n=20 for each)	5.20	0.76	5.60	0.87	0.092^{NS}	3.80	0.83	8.20	1.06	0.186^{NS}
30 (n=20 for each)	7.50	0.68	8.20	1.06	0.18^{NS}	2.80	0.80	5.70	1.08	0.128^{NS}
40 (n=20 for each)	10.10	1.19	10.0	1.12	0.300^{NS}	9.10	1.20	8.20	0.76	0.127^{NS}

SD, standard deviation; pcf, pounds per cubic foot; NS, not significant based on the independent *t*-test; p < 05.

3.3. Angulated lateral displacement test

The mean compressive force required to displace zirconia micro-implants did not differ significantly from that required to displace titanium alloy micro-implants at any distances or angulations

(p > 0.05, independent t-test) (Figure 5, Table 4, 5). Similarly, the mean tensile force required to displace zirconia micro-implants did not differ significantly from that required to displace titanium alloy micro-implants at any distances or angulations (p > 0.05, independent t-test) (Figure 6, Table 6, 7). As the angulation increased, the mean compressive and tension forces required to displace both types of micro-implants increased significantly at all distances (p < 0.05, one-way ANOVA). However, there was no significant difference between materials (p > 0.05). In addition, two-way ANOVA did not show any significant interaction between materials and angulations (p > 0.05) (Table 4, 5, 6, 7).

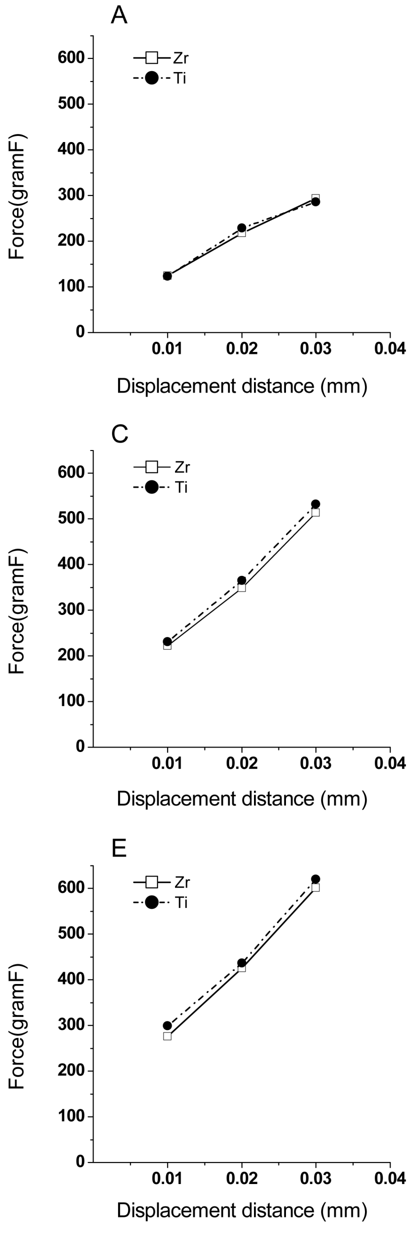

Fig. 5.

Lateral displacement for compressive force according to angulations (A) 0°, (B) 10°, (C) 20°, (D) 30°, (E) 40°.

Table 4. Mean Compressive Force Levels (Mean Ncm ± SD) Recorded at 0.01 mm, 0.02 mm, and 0.03 mm Displacement and Angulation in Each Group.

Angulated Compressive Force Vectors												
	0°				10°				20°			
	Zirconia		Titanium		Zirconia		Titanium		Zirconia		Titanium	
Distance (mm)	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD
0.01	124.41 [w]	25.90	123.09 [a]	19.91	174.21 [x]	27.08	184.56 [b]	23.79	216.67 [y]	35.24	230.68 [c]	30.06
0.02	217.32 [w]	22.52	228.72 [a]	33.03	268.93 [x]	33.30	281.92 [b]	35.25	348.50 [y]	34.21	365.38 [c]	27.84
0.03	293.38 [w]	32.05	285.98 [a]	31.54	443.10 [x]	35.64	432.65 [b]	37.82	513.99 [y]	31.45	532.30 [c]	36.58

Statistical comparisons of the zirconia micro-implant values and titanium micro-implant values at different angles.

SD, standard deviation; NS, not significant; *p*-values are derived from the results of material factors in two-way ANOVA ($p < 0.05$). Superscripts indicate the same groups from a Tukey *post-hoc* test of one-way ANOVA at the same distance in both titanium and zirconia micro-implant groups. There were no statistically significant differences between materials ($p > 0.05$).

Table 5. Continued.

Angulated Compressive Force Vectors									
	30°				40°				
	Zirconia		Titanium		Zirconia		Titanium		
Distance (mm)	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	*p*-value
0.01	261.32^{z}	36.81	270.47^{d}	21.44	275.80^{z}	34.48	299.04^{d}	29.29	NS
0.02	415.56^{z}	35.16	394.45^{c}	34.59	425.77^{z}	34.40	436.60^{d}	36.42	NS
0.03	579.76^{z}	43.57	593.87^{d}	29.28	601.43^{z}	50.46	620.67^{d}	41.72	NS

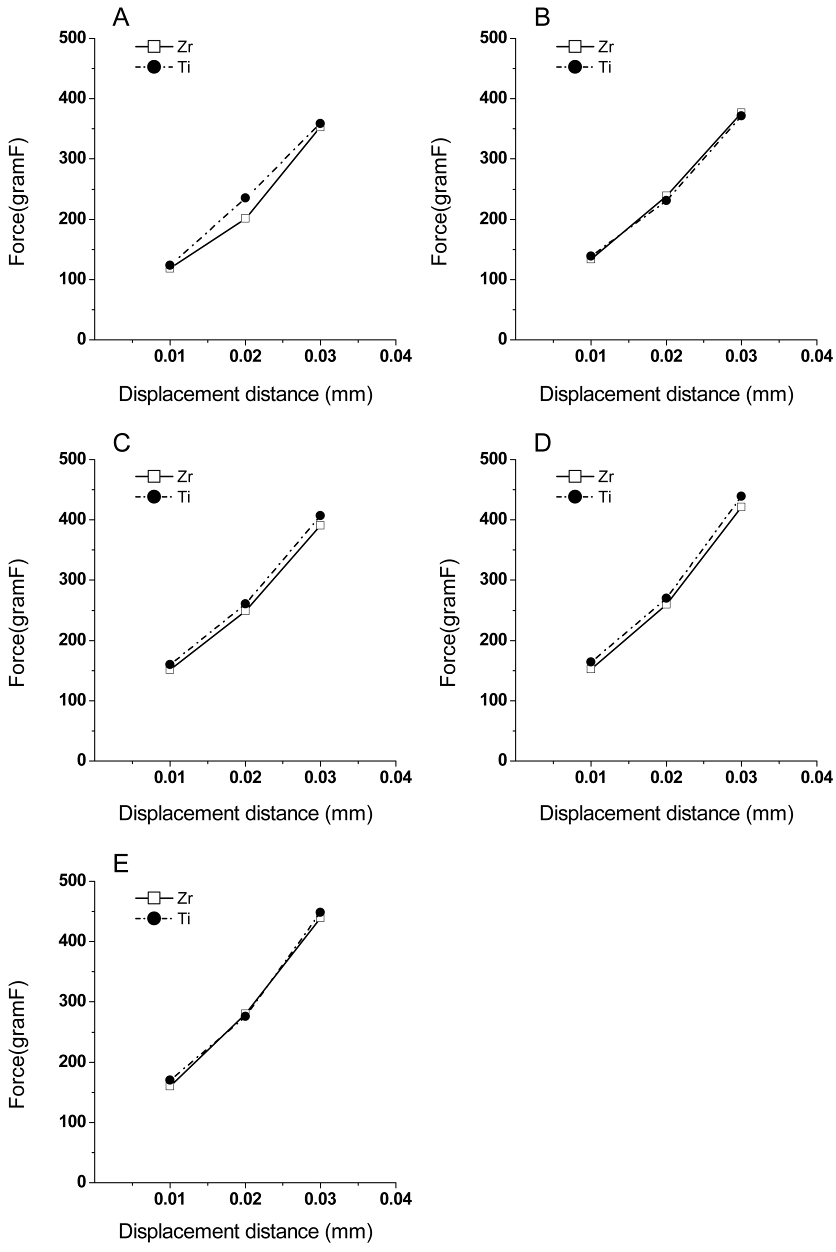

Fig. 6.

Lateral displacement for tensile force according to angulations (A) 0°, (B) 10°, (C) 20°, (D) 30°, (E) 40°.

Table 6. Mean Tensile Force Levels (Mean Ncm ± SD) Recorded at 0.01 mm, 0.02 mm, and 0.03 mm Displacement and Angulation in Each Group.

Angulated Tensile Force Vectors												
	0°				10°				20°			
	Zirconia		Titanium		Zirconia		Titanium		Zirconia		Titanium	
Distance (mm)	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD
0.01	118.29 y	23.03	123.57 a	22.63	128.63 yz	26.09	139.14 ab	25.26	142.72 z	28.91	159.90 bc	35.09
0.02	201.24 x	27.18	235.18 a	40.10	238.31 y	34.04	231.09 a	44.07	248.69 yz	37.80	260.35 ab	32.39
0.03	352.56 x	45.74	358.62 a	38.81	376.53 x	41.01	371.13 ab	36.43	391.28 xy	51.05	407.01 bc	40.65

Statistical comparisons of the zirconia micro-implants and the titanium micro-implants at different angles.

SD, standard deviation; NS, not significant; *p*-values are derived from the results of material factors in two-way ANOVA ($p < 0.05$). Superscripts indicate the same groups from a Tukey *post-hoc* test of one-way ANOVA at the same distance in both titanium and zirconia micro-implant groups. There were no statistically significant differences between materials ($p > 0.05$).

Table 7. Continued.

Angulated Tensile Force Vectors									
	30°				40°				
	Zirconia		Titanium		Zirconia		Titanium		
Distance (mm)	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	Mean (gf)	SD	*p*-value
0.01	152.65^{z}	29.92	163.81^{bc}	34.17	159.86^{z}	33.18	170.41^{c}	32.47	NS
0.02	260.01^{yz}	34.91	269.73^{ab}	42.97	279.71^{z}	40.19	275.46^{b}	33.05	NS
0.03	421.01^{yz}	38.26	438.97^{cd}	42.77	439.06^{z}	37.53	448.13^{d}	42.03	NS

3.4. Histomorphometric analysis

All prototype zirconia micro-implants remained stable during the healing period, and appeared to be clinically osseointegrated. The mean BIC of prototype zirconia micro-implants was 56.88 ± 6.72% (Figure 7).

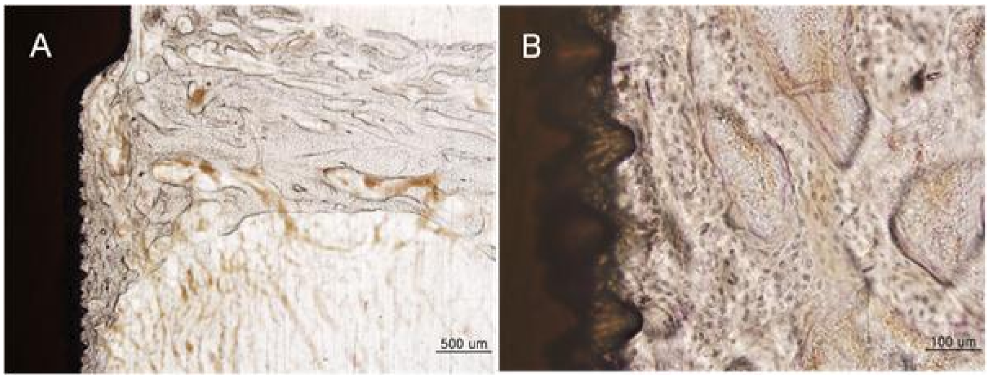

Fig. 7.

Undecalcified, ground and polished section stained with hematoxylin−eosin. Direct contact between bone and implant surface; (A) Enlargement 1.25-fold, (B) Enlargement 20.00-fold.

4. Discussion

Inflammation caused by micro-implants has multifactors such as level of patient hygiene, type of surrounding tissue, and micro-implants head design. [20] Especially, it should be focused that the increase of titanium ion concentration have been found in the vicinity of titanium implants induced by corrosion, which results in undesirable immune reaction followed by peri-implantitis of dental implants. [21] In addition, corrosion is suggested as a confounding factor in the fracture of titanium micro-implants from the fractographic analysis of dental implants. [22] Hydrogen from acidic solutions and fluorine reduce the stability of the passive layer formed on titanium micro-implants surfaces, which is detrimental to its corrosion resistance. [23] Partial interaction between the micro-implant surface and tissue has been observed in retrieved micro-implants, [7] implying micro-implants could be affected by these procedures. Another study reported titanium allergy on titanium implants with a prevalence of 0.6%. [24]

Recently, high strength yttrium-stabilized tetragonal zirconia polycrystals have been introduced as a substitute for titanium implants. They exhibited inertness in the tissue and minimal ion release compared with metallic implants in addition to higher fracture resilience and higher flexural strength. [25, 26] Butz et al. [27]

reported that zirconia abutments were comparable to titanium ones when the survival rate, fracture strength, fracture rate and failure mode of the abutments were evaluated after chewing simulation and fracture loading.

The orthodontic micro-implants showed differences with conventional dental implants in some ways such as duration of use, amount of osseointegration, and surface characteristics. [3] However, investigation of dental implant literature may offer some insight for the interaction of micro-implant and tissue.

Regarding bacterial adhesion, studies showed that zirconia exhibited lesser bacterial accumulation than titanium counting the total number of bacteria and presence of putative pathogens. [11, 28] Teughels W. et al. [29] reported that the composition and surface characteristics of the different substrates used for implant components may have direct influence on the adhesion, proliferation and colonization of micro-organisms found in oral biofilm, which affect the pathogenesis of peri-implantitis and implant loss. The inflammatory response and bone resorption induced by ceramic particles were reported much lesser than those induced by Ti6Al4V when implanted onto murine calvariae implying the biocompatibility of ceramics. [10] Thereby, these results support zirconium oxide as a possible desirable micro-implant material.

In addition to material composition, surface topography of a biomaterial is pivotal for secondary stability of implants. Sandblasted and acid-etched (SLA) surface treatment and loadings showed significant effects on bone surrounding the micro-implants, which is related to greater osseointegration and higher success rates. [30] Therefore, various chemical and physical surface modifications have been developed to improve osseointegration, such as providing the micro-roughness or bioactive coatings. [31] Similarly, diverse methods of fabrication of zirconia implants are investigated to allow the surface roughness of machined zirconia implants for improved osseointegration. [31] Neverthless, it has been difficult to accomplish the roughened surface using conventional methods because of the bio-inert nature and superior hardness of the material. [32]

In recent years, powder injection molding (PIM) technique was introduced to achieve surface roughness in zirconia implants instead of machining methods, which enabled to have simplified and economically advantageous mass production. [15] Thus, zirconia micro-implants with PIM technique can be an comparable alternative to conventional titanium micro-implants. However, the optimal extent of roughness of zirconia micro-implant for osseointegration is not clear still. [33] Well-designed studies examining the optimal surface characteristics of zirconia micro-implants and biomechanical and histomorphometrical investigations is needed to be examined in the future studies.

Among the methods for assessing implant stability, insertion torque is often measured in determining initial stability. [16] Considering the various designs of micro-implants and bone densities result in the diversity of insertion torque, [16] torque tests were accomplished on diverse simulated cortical bone densities because the density of bone varies depending on its location. [18] Besides, removal torque is proved as a reliable measurement of stability and should be comparatively high to prevent unscrewing. [34] In this study, the MIT and MRT of zirconia micro-implants showed no statistically significant difference with titanium alloy micro-implants with similar design. However, both groups recorded considerably higher amount comparing with cylindrical design in previous study due to its tapered shape and surface characteristics. [17]

Conical shape of micro-implants are considered to enhance the initial stability because it allows mechanical retention and more contact with cortical bone. [19] The tapered design of zirconia micro-implant allow sufficient width in the neck area to avoid concentrating stress leading to possible fracture. In addition, it provided better control during insertion by reducing the wiggle effect, one of the factors associated with mini-implant failure, because the upper part of the taper shape has a large diameter than the lower part. [35] Therefore it could have some advantages such as mechanical retention and better primary stability as reported in the previous studies. [36, 37]

Numerous researches suggested that a certain range of insertion torque values needed for the success of micro-implants. [38] Excessive insertion torque might cause detrimental effects such as increased bone micro-damage, which potentially contributes to failure of micro-implants. [39] The current study showed that the MIT range of zirconia micro-implants was within this physiologic insertion torque range of 5 to 10 Ncm in 20 and 30 pcf biosynthetic bone, [40] however mean MIT in 40 pcf (10.15 Ncm) is approaching the upper limit (Table 3). The tapered design of zirconia micro-implants is suggested to enhance mechanical stability without the increase in microdamage considering microfracture is reported to be associated with the greater diameter rather than with the tapering of micro-implant. [39] The surface treatment may contribute to the increased insertion torque, whereas it can promote the secondary stability. [30, 31] However it showed higher insertion torque in 40 pcf bone simulants, fracture of micro-implants was not observed in this study. Nevertheless pilot drilling is recommended in high dense cortical bone area and zirconia micro-implants may not be ideal for insertion into areas of high bone density. Small diameter of micro-implants includes the drawbacks such as fracture while insertion, and loosening because of decreased initial stability. [41] Thus the diameter of 1.6mm has been chosen as a balance with microdamage of cortical bone and mechanical property for initial stability. [39]

Unlikely dental implants that are supposed to have axial loading, orthodontic micro-implants should withstand forces applied perpendicular to their long axis. In this study, the lateral displacement test measures the force applied to micro-implants with angulation rather than vertical force, which simulate how orthodontic forces are applied on micro-implants. [17] Regarding initial mobility, which is the crucial for micro-implants success, the force was recorded when initial movement was identified at microlevels of 0.01, 0.02, and 0.03 mm. [42] Zirconia micro-implants showed suitability to stand the orthodontic force because the force required for 0.02 mm displacement exceeded 200 g, taking consideration into the optimal orthodontic force range required for tooth movement is less than 200 g.

The mean compressive and tensile force required to displace the zirconia micro-implant showed no statistically significant difference with that required for the titanium alloy micro-implant at all distances and at all angulations (Table 4, 5, 6, 7). In this study, the force for the displacement of 0.01 mm, 0.02 mm, and 0.03 mm was recorded, which is decreased amount comparing other study that reported the critical threshold of 50 μm to 150 μm for micromovement of dental implants. [42] Thus, the zirconia micro-implants can be assumed to withstand sufficient force for initial stability.

The compressive force required to displace both micro-implant groups increased gradually as the angulation increased (Figure 5, Table 4, 5). As the angulation of compression force increased, the vertical force vector directed along the long axis of the micro-implants increased and the horizontal force vector directed perpendicular to the long axis of the micro-implant decreased. This suggested more evenly distribution of stress to bone simulant and increased underlying bone support against compressive force, which explained elevated compressive force to displace the micro-implants.

Similarly, during the application of tensile force, the stress distribution became even as the angulation of the force vector increases into the implant thread and surrounding bone simulant, following more tension force is required for lateral displacement (Figure 6, Table 6, 7). Pickard et al. [43] speculated pull-out forces for various angulations of orthodontic mini screws, relative to the direction of applied force. The pull-out force was greatest for those orthodontic micro-implant angulated toward the direction of applied force, and gradually decreased as the lateral force vector increased, whereas, those placed at an angle opposing the applied force showed the least. The FEM study corroborated this result that decreased angulation of applied force induced in less uniformity of the load distribution on the screw threads and disproportionate loading of the surrounding bone. [44]

In the experimental biological study, the overall BICs of prototype of zirconia micro-implants was 56.88 ± 6.72%, suggesting higher than that of titanium micro-implants comparable with values reported in another study. [45] It meant that the prototype of zirconia micro-implants showed comparable biocompatible characteristics with titanium micro-implants.

The results of the current study suggest that the zirconia micro-implants can be used clinically with power chains, coil springs, and elastics, as it can withstand light orthodontic compressive and tensile forces of 150–200 g at all angles. Especially, the zirconia micro-implant has the potential for clinical application for patients with nickel allergy, poor oral hygiene, high esthetic demand, and may provide financial advantage. Further, randomized clinical trials and in vivo studies examining bone remodeling and cellular responses to zirconia micro-implants are required to confirm the findings of this mechanical study.

5. Conclusions

The zirconia micro-implants used in this study demonstrated acceptable initial stability without fracture during the tests.

Both torque and angulated lateral displacement tests under compressive and tensile forces indicated that the zirconia micro-implants showed comparability with titanium alloy micro-implant in the primary stability and clinical applicability.

The biological study indicated that the prototype of zirconia micro-implants showed biocompatible characteristics.

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국문 초록

지르코니아와 타이타니움 합금 교정용 마이크로 임플란트의 초기 안정성과 임상적 유용성에 관한 비교 연구

서울대학교 대학원 치의과학과 치과생체재료과학 전공
(지도교수 이 상 훈)

최 혜 원

Powder injection method (PIM)를 이용하여 제조된 교정용 지르코니아 마이크로 임플란트와 기존의 교정용 타이타니움 합금 마이크로 임플란트와의 기계적 및 생물학적 연구를 시행하여 초기 안정성과 임상적 유용성을 비교하였다. 60 개의 교정용 지르코니아 마이크로 임플란트(직경, 1.6 mm; 길이, 8.0 mm)와 동량의 유사한 디자인의 교정용 타이타니움

마이크로 임플란트를 20 pounds per cubic foot (pcf), 30 pcf, 40 pcf 의 다양한 밀도를 가진 polyurethane foam 에 수직으로 식립한 후, Maximum insertion torque (MIT)와 Maximum removal torque (MRT)를 측정하여 초기 안정도를 평가하였다. 측방 변위실험을 위해 마이크로 임플란트를 수직으로 식립하고 임플란트의 장축의 직각방향에 대해 0°, 10°, 20°, 30°, 40° 의 다양한 각도로 압축력과 인장력을 가하여 0.01 mm, 0.02 mm, 0.03 mm 의 변위를 야기하는 힘의 값을 기록하였다. 또한 동물실험을 통하여 교정용 지르코니아 마이크로 임플란트의 생체적합성을 조사하였다. 그 결과 MIT, MRT, 다양한 각도의 측방 변위실험에서 교정용 지르코니아 마이크로 임플란트와 교정용 타이타니움 임플란트 사이의 통계적으로 유의할 만한 차이가 발견되지 않았다. 측방 변위실험에서 모든 변위량에서 각도가 증가할수록 측정되는 평균 압축력과 인장력의 크기가 증가되었다. 또한 동물실험에서 56.88 ± 6.72%의 Bone-implant-contact ratio 를 나타내었다. 이상의 결과에서 압축력과 인장력을 가했을 때, 교정용 지르코니아 마이크로 임플란트는 교정용 타이타니움 임플란트와 비교하여 유의성 있는 차이가 없는 초기 안정성과 임상적 유용성을 나타내었다. 향후 교정력 하에서 교정용 지르코니아 마이크로 임플란트의 이차 안정성에 대한 연조직 및 세포 반응 실험과 전향적 임상시험이 필요할 것으로 사료된다.

주요어 : 마이크로 임플란트, 지르코니아 임플란트, 교정용 골성 고정원, 기계적 안정성

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